

Prospects for the Higgs Boson Searches with CMS

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An overview on the prospects for the Higgs boson searches with the CMS detector is presented. Projections have been made to estimate the potential to a possible discovery or exclusion of the Higgs boson during the run at a center of mass energy of 7 TeV/c² at LHC, with a recorded integrated luminosity of approximately 1 fb⁻¹, conditions expected by the end of 2011.

I. CURRENT STATUS OF HIGGS SEARCHES

At the end of the Large Electron Positron (LEP) operations, an exclusion limit was reached by combining the results of all the Higgs search channels performed by its four experiments, establishing a lower limit on M_H of 114.4 GeV/c² at 95% confidence level.

More recently, the direct Higgs searches performed by the CDF and D0 experiments at the Tevatron accelerator have reached better sensitivity, making possible the exclusion of a SM Higgs Boson with a mass between 158 and 174 GeV/c².

II. HIGGS PRODUCTION AND DECAY MODES AT THE LHC

The LHC is continuously collecting luminosity at a center of mass energy of 7 TeV/c² since March 2010. The projected luminosity to be delivered before the shut-down to go to higher energies is 10 pb⁻¹ by November 2010 and 1 fb⁻¹ by the end of 2011.

The main production modes for the Standard Model (SM) Higgs at 7 TeV/c² at the LHC, presented in Fig. 1a, are: gluon gluon fusion (gg), dominant in the whole mass ranges; vector boson fusion (VBF, qqH), increasingly important for high masses and leading to a characteristic signature in the final state with two forward jets and associated production, with W and Z boson or top quarks (WZ, ZH, t \bar{t} H), that is relevant in the low mass region and allows for easy triggering.

Concerning the decay modes, presented in Fig. 1b, for low masses ($M_H < 2M_Z$), $H \rightarrow b\bar{b}$ decay has the highest branching ratio, although this channel is experimentally challenging due to the huge QCD background present. Another important decay mode for low masses is $H \rightarrow \tau\tau$, accessible through VBF, and $H \rightarrow \gamma\gamma$, in which the Higgs mass peak can be reconstructed with good resolution. For high masses ($M_H > 2M_Z$), the $H \rightarrow t\bar{t}$ decay can be studied, however, it presents difficulties in the selection due to the small signal-to-noise ratio.

The $H \rightarrow WW^*$ and $H \rightarrow ZZ^*$ decay channels are powerful in the whole mass range. The Higgs decay into W bosons gives the earliest sensitivity and it is the dominant decay mode for a wide mass range. Higgs to ZZ^* has a very clean experimental signature with four leptons where a narrow mass peak is reconstructed above a smoothly varying background.

A. LHC AND Tevatron Scenarios

The Higgs searches at CMS during the LHC first period of data taking will overlap with the last runs of the Tevatron experiments, CDF and D0. By the end of 2011, the Tevatron is expected to have 10 fb⁻¹ at a center of mass energy of 1.96 TeV/c² compared with 1 fb⁻¹ at 7 TeV/c² for the LHC.

To give a rough estimate of the expected performance of LHC with respect to Tevatron the different parton luminosities of the two colliders need to be taken into account.

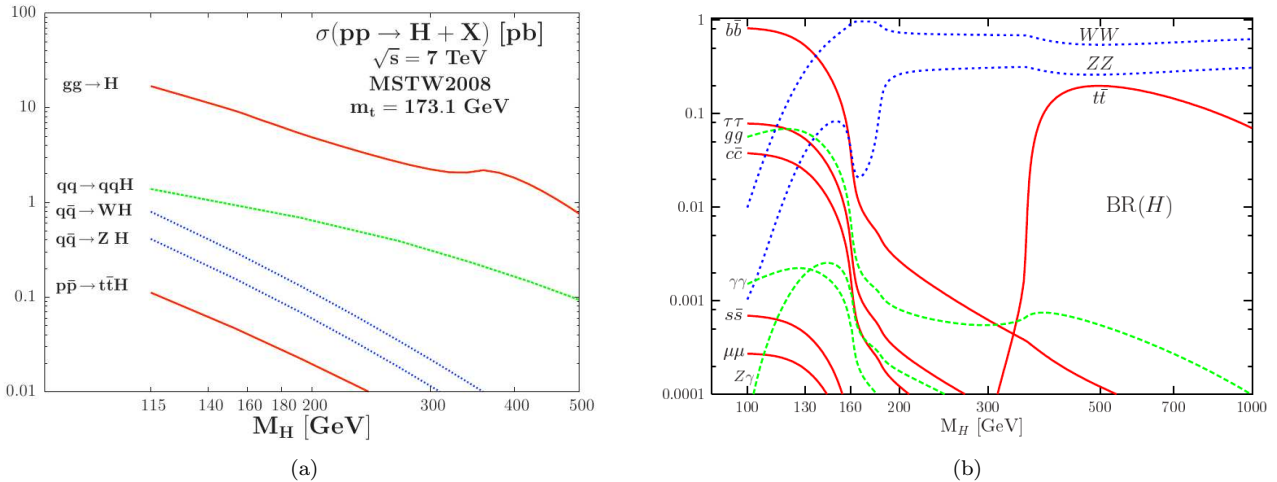


FIG. 1: Standard Model Higgs production cross sections for a proton proton collider with 7 TeV/ c^2 center of mass energy (a) and decay modes (b). The cross sections of the various processes and the branching ratios are presented as a function of the Higgs boson mass.

In the high mass regime ($M_H > 140 \text{ GeV}/c^2$) gluon gluon luminosity at LHC is more than 15 times higher than at Tevatron. Being the dominant background to the main channels ($H \rightarrow ZZ$ and $H \rightarrow WW$) mainly produced by $q\bar{q}$ which rises relatively slowly it can be concluded that LHC will be competitive with 1 fb^{-1} .

Contrary in the low mass region the rise in the cross section is less pronounced and the $q\bar{q}$ processes (e.g. Higgsstrahlung) are not so favorable at LHC compared to at Tevatron. The signal to background ratio is also worsen by the dominant gluon fusion mechanism which enhances the main backgrounds channels (e.g $t\bar{t}$, $W/Zb\bar{b}$). The previous considerations suggest to use the challenging $\gamma\gamma$ mode.

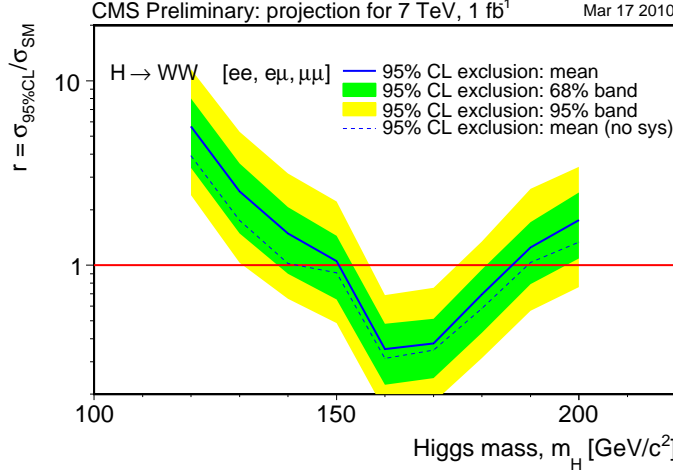
B. Prospective Higgs Searched at CMS

The CMS experiment utilizes a wide range of Higgs decay channels and have public results available for different \sqrt{s} . The Higgs sensitivity at 7 TeV/ c^2 with 1 fb^{-1} , has been studied using projections made from the results obtained using Monte Carlo samples at different center of mass energies, namely 10 and 14 TeV/ c^2 .

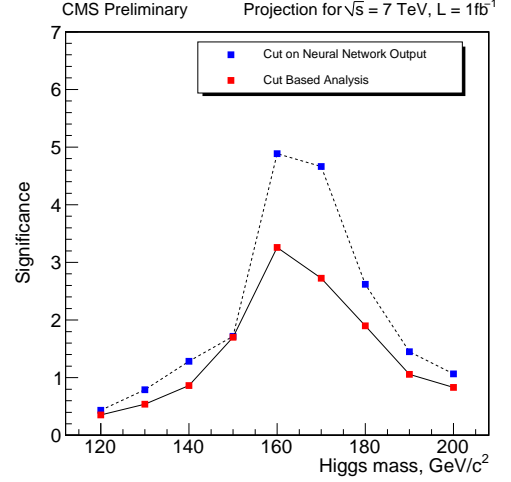
These projections are not new analysis done with 7 TeV/ c^2 Monte Carlo samples and new detector simulation and reconstruction software. They are done starting from public results at 10 and 14 TeV/ c^2 . The signal and background event counts have been re-scaled by the ratio of 7 TeV/ c^2 to 14 TeV/ c^2 cross-sections and then normalized to 1 fb^{-1} . No corrections for higher acceptance at smaller \sqrt{s} or for improvements in the reconstruction are applied. Systematic and statistical uncertainties have been also re-scaled conservatively.

III. SM HIGGS SEARCH CHANNELS AT THE LHC

The main Higgs search channels relevant for the current running conditions of the LHC will be presented in the following.



(a)



(b)

FIG. 2: Exclusion limit (a) and discovery sensitivity (b) for the Standard Model Higgs boson decay mode WW. The results are obtained with projections for an integrated luminosity of 1 fb^{-1} at $7 \text{ TeV}/c^2$.

A. Higgs to WW*

The $H \rightarrow WW^* \rightarrow ll\nu\nu$ decay channel is considered the discovery channel for a SM Higgs boson in a wide mass range at the LHC. The Higgs to WW^* branching ratio is close to 1 in the $2M_W < M_H < 2M_Z$ mass range and the leptonic decay of the W bosons gives a clear experimental signature characterized by the two high p_T leptons with opposite charge and a small transverse opening angle.

Missing transverse energy is also expected, due to the undetected neutrinos. No central jet activity is characteristic of the $gg \rightarrow H$ process while two high rapidity jets are expected for the VBF process (smaller cross-section).

The backgrounds to consider in the analysis are all sources of real or fakes multi-lepton final states and missing E_T , like the irreducible continuum WW production (plus other di-boson processes such as WZ and ZZ), $t\bar{t}$ process, Drell-Yan and W+jets, amongst others.

The CMS analysis consider the three final states ee , $\mu\mu$ and $e\mu$. As no mass peak can be reconstructed due to the presence of the neutrinos, the best knowledge of the backgrounds is mandatory. This is achieved by using control regions and data-driven methods. The systematic uncertainties are carefully addressed.

Different approaches have been studied. A sequential cut-based analysis independently optimized for the three considered final states in the 0-jet bin ($H+0j$), a multivariate analysis considering all the three final states together and a dedicated study for the VBF channel.

For an integrated luminosity of 1 fb^{-1} at $7 \text{ TeV}/c^2$, as shown in Fig. 2a and Fig. 2b, exclusion would be possible at 95% CL in this channel from around 140 to 180 GeV/c^2 , and discovery level sensitivity (5σ) would be achieved for masses around 165 GeV/c^2 .

B. Higgs to ZZ*

The $H \rightarrow ZZ^* \rightarrow llll$ decay channel is known as the golden Higgs decay, as it has the cleanest experimental signature for discovery with a narrow four-lepton invariant mass peak on top of a smooth background. It is powerful in a wide high mass range, however it can be a challenge for Higgs masses between 120 and 150 GeV/c^2 , where one of the Z bosons is off-shell.

In the analysis two pairs of same flavor, opposite-sign leptons ($4e$, 4μ , $2e2\mu$), are selected and the Higgs mass is

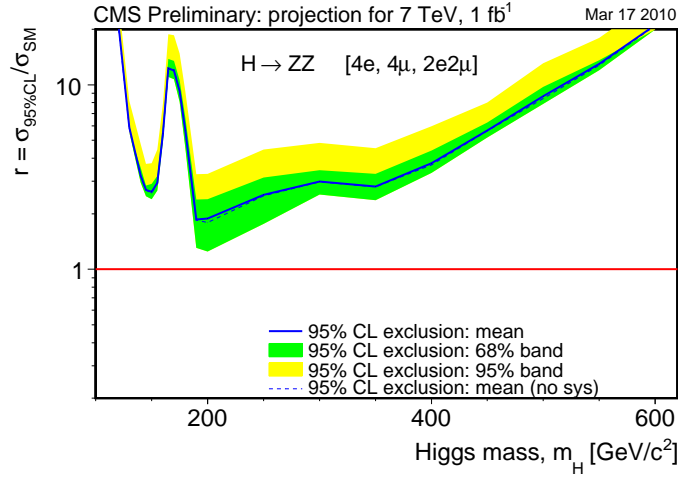


FIG. 3: Exclusion limit for the Standard Model Higgs boson decay mode ZZ^* . The results are obtained with projections for an integrated luminosity of 1 fb^{-1} at $7 \text{ TeV}/c^2$.

reconstructed. The main backgrounds are the irreducible ZZ^* , $Zb\bar{b}$ and $t\bar{t}$. Due to the presence of two non-isolated and displaced leptons the last two can be largely reduced with isolation and impact parameter cuts. The rate of the ZZ is assessed from data Z events.

With an integrated luminosity of 1 fb^{-1} at $7 \text{ TeV}/c^2$, as shown in Fig. 3, the SM Higgs boson cannot be excluded anywhere in the entire mass range.

However, the Higgs boson with a mass $M_H < 400 \text{ GeV}/c^2$ would be excluded, if a fourth generation of quarks exists. Indeed an extra doublet of quarks would make the gluon fusion production rate about 9 times larger, regardless of how massive the two extra 4^{th} generation quarks might be.

C. Higgs to $\gamma\gamma$

In the low mass range, $110 < M_H < 140 \text{ GeV}/c^2$, $H \rightarrow \gamma\gamma$ is a promising channel. Two high energy isolated photons in the final state allow for a mass peak reconstruction, but due to the small branching ratio, this channel is considered a high luminosity analysis.

The backgrounds are the irreducible $\gamma\gamma$, γ +jets, jets and Drell-Yan. The background can be assessed from the sidebands. CMS has proposed two complementary analyzes: a cut-based and an event-by-event kinematic likelihood ratio.

For an integrated luminosity of 1 fb^{-1} at $7 \text{ TeV}/c^2$ as shown in Fig. 4 the SM Higgs boson cannot be excluded anywhere in the entire mass range.

The case of a fermiophobic Higgs would largely suppress the gluon fusion cross section enhancing at the same time the $\gamma\gamma$ decay mode. Under this condition and assuming a conservative selection it would be possible to improve the SM exclusion limit by a factor four or down to $110 \text{ GeV}/c^2$.

Fig. 5 shows the projected exclusion limits for a SM Higgs by combining results of the $H \rightarrow WW^*$, $H \rightarrow ZZ^*$, and $H \rightarrow \gamma\gamma$ channels. The expected exclusion mass range is $145 < M_H < 190 \text{ GeV}/c^2$. The Higgs boson with a mass $M_H < 500 \text{ GeV}/c^2$ would be excluded, if a fourth generation of heavy quarks exists.

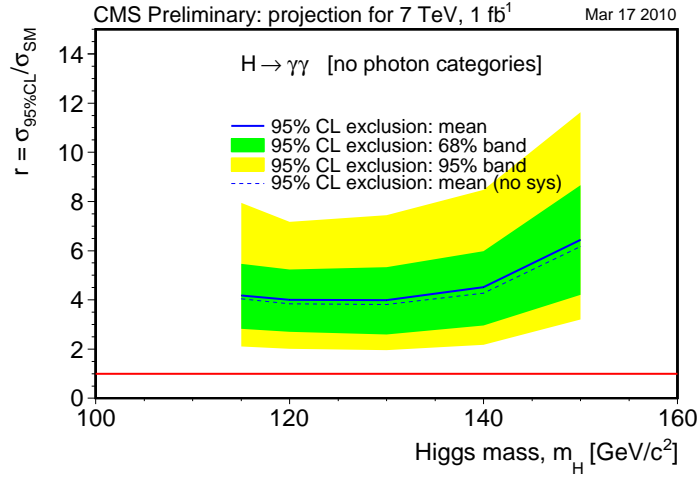


FIG. 4: Exclusion limit for the Standard Model Higgs boson decay mode $\gamma\gamma$. The results are obtained with projections for an integrated luminosity of 1 fb^{-1} at $7 \text{ TeV}/c^2$.

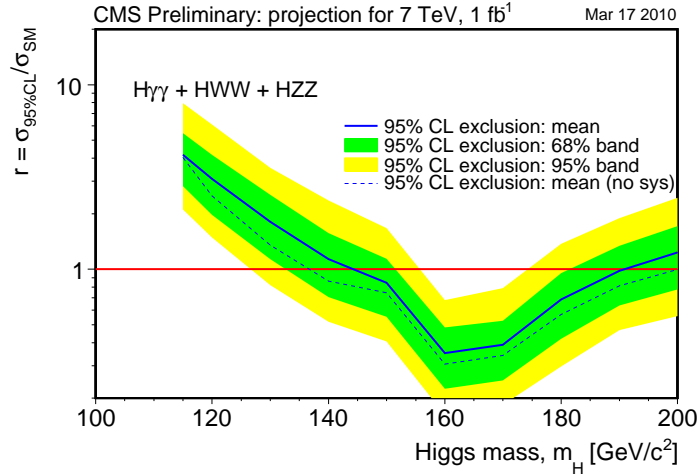


FIG. 5: Combined exclusion limit for the Standard Model Higgs boson. The results are obtained combining the results of the projections for an integrated luminosity of 1 fb^{-1} at $7 \text{ TeV}/c^2$ of three decay modes: WW, ZZ* and $\gamma\gamma$.

IV. MSSM HIGSS SEARCHES CHANNEL AT THE LHC

The main channel for minimal Super Symmetric Standard Model (MSSM) Higgs searches in the first period of running of the LHC will be heavy neutral MSSM Higgs Φ produced via b quark association with subsequent decay to τ , $b\bar{b}\Phi$, $\Phi \rightarrow \tau\tau$.

The main backgrounds are $Z+b\bar{b}/c\bar{c}/\text{jets}$ and $t\bar{t}$. In the proposed analysis final states with isolated pairs of τ decaying to hadrons and leptons are selected. Missing E_T is also required as well as one b-tagged jet and a veto on extra jets in the event.

The analysis is performed by counting events in the $\tau\tau$ invariant mass window, reconstructed by collinear approximation where the τ decay products are assumed to be in the same direction as the τ itself.

Fig. 6 shows the projected discovery and exclusion contours in the MSSM (M_A , $\tan\beta$ -plane) for the search for a

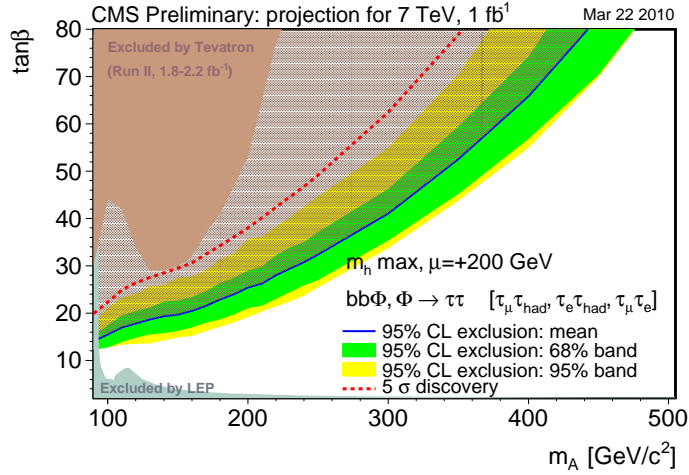


FIG. 6: Exclusion and discovery contours for a neutral MSSM Higgs boson in the $pp \rightarrow b\bar{b}\Phi$, $b\bar{b}\tau\tau$ channel. The results are obtained with projections for an integrated luminosity of 1 fb^{-1} at $7 \text{ TeV}/c^2$.

neutral MSSM Higgs bosons in the $pp \rightarrow b\bar{b}\Phi$, $b\bar{b}\tau\tau$ channel with the CMS experiment. At $M_A \approx 90 \text{ GeV}/c^2$, discovery is possible for $\tan\beta > 20$ and the exclusion limit is expected to reach down to $\tan\beta > 15$.

V. CONCLUSIONS

The performance of the CMS detector in collision data has been very good since the beginning of the data taking allowing to produce the first results after few hours.

The reconstruction of the main physics objects used in the Higgs analysis is performing well and it is already possible to start exploring Standard Model processes, namely W and Z.

At $7 \text{ TeV}/c^2$, with enough luminosity (1 fb^{-1}), the CMS experiment will begin to explore a sizable range of Higgs mass, reaching SM Higgs discovery sensitivity for masses between 160 and 170 GeV/c^2 and exclusion between 140 and 200 GeV/c^2 , while low mass SM Higgs searched will require higher center of mass energy and integrated luminosity.

For MSSM Neutral Higgs the discovery range at $\sqrt{s} = 7 \text{ TeV}/c^2$ for small M_A would be $\tan\beta > 20$ and exclusion be possible down to $\tan\beta \approx 15$.

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